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PROBLEMS AND SOLUTIONS IN THE
FABRICATION OF H-FILM (KAPTON)
FLEXIBLE CIRCUITS

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INTRODUCTION

H-film, or Kapton as it is now known, is the registered trademark name of a polyimide film manufactured by DuPont. It is a light amber colored, transparent, tough, flexible film. It is flame resistant, infusible, and will not melt, but will begin to char above 1500°F. There is no known organic solvent, but strong inorganic alkaline solutions will attack it.

The manufacturing process for Kapton is patented and being held proprietary by DuPont. However, the chemical reaction is common knowledge. A simplified version of the reaction is given below (Figure 1). Kapton is a polyimide (or more properly, polypyromellitimide) film, and results from the polycondensation reaction between pyromellitic dianhydride and an aromatic deamine.

Kapton is available in thicknesses of 1/2, 1, 2, 3, and 5 mils and in widths up to 16 inches. The 1 mil Kapton film is supplied by the vendor with 1/2 or 1 mil FEP Teflon bonded to one or both sides. Two mil Kapton is available with 2 mil FEP Teflon bonded to one side.

It is not the intent of this paper to give the fabrication steps involved in constructing Kapton flexible harnesses. This paper will present the major problem areas we have encountered at Martin-Orlando and how we have solved them.

INITIAL TENSILE STRENGTH

H-film or Kapton has an excellent tensile strength of about 25,000 psi. However, we found that the tensile strength of a fabricated Kapton harness varied greatly from harness to harness and did not approach the tensile strength of the film in any harness configuration. We found the reason for this difference in tensile strengths lay in the material used for bonding the Kapton to the copper foil or to itself.

This bonding material is FEP Teflon. It is supplied in various thicknesses and bonded to one or both sides of the Kapton (Figure 2).

We found that the peel strength of the bond between the Kapton and the Teflon varied.

A second cause of lowered tensile strength of the harnesses was found in the bond established during the lamination cycle of Teflon to copper foil and/or the Teflon to itself (Figure 3). We discovered that the peel strength of these bond lines varied considerably and was entirely dependent on the proper time, temperature, and pressure, and the close control of each in the lamination cycle.

We found that we obtained optimum bond strengths by assuring that:

- 1 The Teflon was preheated to its plastic state before pressure was applied;
- 2 Sufficient pressure was applied to eliminate all air;
- 3 The harness was cooled under pressure to below the temperature of the Teflon.

A third cause for lowered tensile strength was found to be in the very poor tear resistance of the Kapton. We found that the slightest nick or tear in the edge of a trimmed harness would cause the tear to easily extend across the entire film with very little tensile pull. This can be overcome by using sharp, smooth, steel rule dies for trimming. The initial tensile strength of a flexible harness fabricated from Kapton, Teflon, and copper foil can present a problem which does not lie with the Kapton film itself, but rather in one or more of these areas:

- 1 Bond peel strength of FEP Teflon to Kapton, as supplied by the vendor;
- 2 Bond peel strength of FEP Teflon to itself or to copper foil as obtained during the lamination cycle;
- 3 The inherent poor tear resistance of Kapton.

There are other factors that enter into the initial tensile strength of a fabricated harness such as cleanliness of all parts during layup and lamination, the use of virgin FEP Teflon rather than reprocessed degraded material, and control of environmental conditions during storage and layup prior to lamination.

HOLE PUNCHING

There are two concepts of terminal connections on conductor pads currently being used at Martin-Orlando. One method is to solder an eyelet to the terminal pad with a high temperature solder alloy prior to lamination of the cover layer (Figure 4).

The second method is to use a clearance hole in the cover layer at each terminal pad (Figure 5). Both methods necessitate punching holes in the Kapton cover layer prior to lamination. Because of the flexible, tough, elastic nature of Kapton, the punching of clean, sharp, nick and burr free holes by conventional methods presented a problem.

Special punch and die sets were designed and fabricated with extremely close tolerances in an attempt to get a clean, sharp hole. However, the slightest nick or attempt to remove a burr resulted in a tear in the film.

We have attempted to solve this problem by designing, fabricating, and proof testing a punching tool we call a "Ball Piercing Tool". There is a patent disclosure by Martin-Orlando on this concept.

When a sheet of Kapton is placed between the top and retainer plates of the tool and the assembly placed between the platens of a flat bed press or squeezed between the rolls of a roll press, a set of special ball bearings in the tool press down and nip off the Kapton against hardened bushings below. The cut is quick, clean, and uniform. This method has the advantage of cutting all holes at one time. The stretching and distortion of the film is minimized and the holes are reproducible time after time. The tool is easily sharpened by taking a skim grind cut off the face of the bottom plate.

MISREGISTRATION OF CIRCUIT PATTERN

While we were studying and establishing the lamination technique parameters for H-film, we observed that in many instances, the finished harnesses would not register with the master artwork. Figure 6 shows an example of misregistration. This problem was especially troublesome because the misregistration would occur in different areas of harnesses of the same configuration. It was impossible to predict if misregistration was going to occur, and if it did, where would it occur and to what extent.

This unpredictability pretty well eliminated misregistration of artwork and tooling as the cause (although this possibility was checked out). We found the amount of misregistration would vary, that it occurred during one or both fabrication process steps, and that there were secondary conditions that contributed to misalignment problems.

The first process step investigated was the etching of the circuit pattern in the copper. The printing and developing of the image presented no problem, but after etching, the pattern often would not register with the artwork. Our studies showed the following causes:

- 1 The thinness and flexibility of the film caused handling and fixturing difficulties.
- 2 The physical force of the spray etcher caused a stretching and deformation of the film.
- 3 In many cases, tool holes would be torn or deformed by the force of the spray.

These problems were corrected by designing and fabricating a special etching fixture (Figure 7). This fixture is made of epoxy glass material and consists of a back solid plate and a top frame (Figure 8). Both are tooled to a master fixture and the part in production.

The part is placed on the solid back plate. The frame is placed over the part, and stainless steel tooling pins are inserted. The frame is then clamped on all four sides to hold the part firmly in place.

Another cause of circuit movement during the etching process was found to be a result of locked-in stress formed when the copper foil was laminated to the Kapton. This happened during initial bonding on roll laminating presses. It seldom, if ever, occurred on flat bed presses. We believe the reason for this is the relative tension of the rolls of copper foil and the Kapton as they are fed into the roll presses. If there is too much tension on the Kapton, it will stretch. As the copper is removed during etching, the stress is relieved. The Kapton moves to a destressed condition, taking the remaining copper circuit with it, resulting in misalignment.

The current method of overcoming this problem is to relaminate, in a flat bed press, all material that has been roll laminated. By subjecting the Kapton copper foil laminate to controlled heat, the bond of the FEP Teflon is relaxed allowing the Kapton stress to be relieved. Then by

applying pressure and cooling under pressure, the bond is re-established without a stress. This relamination is admittedly a stop-gap measure, and Martin-Orlando is currently working with several roll laminating vendors to correct this condition at its source.

Another process step involved is during the lamination cycle, in which the cover layer is bonded to the etched circuit pattern and substrate. Because the copper circuit pattern is bonded to the Kapton substrate by FEP Teflon, and because the cover layer will be bonded to the substrate by the same material when the bond is made, both the Teflon on the cover layer and bonding of copper to the substrate occurs in a plastic condition. When pressure is applied during lamination, any lateral movement can and does cause the circuit pattern to move, resulting in misalignment (Figure 9). There are several possible solutions to this problem but so far we have found only one workable solution. This solution is in process control. Bond line temperature must be sufficient, but not excessive. Pressure must be sufficient to remove all air but not excessive to cause breakage and movement of conductors and terminal pads.

The type and thickness of press pads have bearing also. The time of the lamination cycle is very important, and the speed at which the pressure is applied is particularly critical.

Since FEP Teflon is a thermoplastic material, there is no cure time required. Therefore, as soon as the bond line is plastic, pressure should be applied. When the air has been purged, there is no need for additional pressure or time and the part should be cooled to the solid stage. By using a press with flat parallel platens, and by properly controlling the lamination cycle parameters, the problem has been solved.

Perhaps a simple solution would be to use a high temperature thermosetting adhesive in place of FEP Teflon so that the adhesive would not reflow during the lamination of the cover layer. Currently Martin-Orlando is investigating several such adhesives, primarily polyamideimides, but as far as we have been able to determine, they are not sufficiently advanced to be incorporated into a manufacturing process.

SOLDERING

This problem was encountered where an eyelet is used in a terminal pad. It was, and is, felt that sufficient reliability of the connection between the terminal pad and the eyelet could only be obtained by soldering the eyelet to the pad prior to the lamination of the cover layer (Figure 4).

A high temperature solder alloy that would not flow during lamination was needed as well as an adequate non-acidic flux. Considerable study and research went into solving this problem. After investigating various amounts of solder, alloys, fluxes, pretinned eyelets, etc., Martin decided to use 5/95 solder alloy preforms which render the correct amount of solder for each joint. The alloy has lower liquidous temperature than pure lead. However, the flow characteristic of the alloy more than offsets the temperature difference. The flux used is an activated, non-corrosive substance as supplied by a vendor. All eyelets are hand soldered and operator skill is quite critical.

DELAMINATION

This problem has been touched upon in the discussion of mis-registration of circuit pattern, but the problem is of such magnitude and frequency, that it deserves a more detailed treatment. The majority of delamination failures could be placed in three categories:

- 1 Insufficient and uneven temperature;
- 2 Contaminated and/or improper copper surface;
- 3 Release of pressure at too high temperatures.

1. Insufficient and Uneven Temperature

While FEP Teflon begins its plastic stage at about 475 to 490°F, optimum laminating temperature is 565°F. While a bond can be achieved at a lower temperature, the bond strength is lower due to the lowered Teflon plasticity. Higher temperatures are not advisable because Teflon begins to degrade.

Where delamination was found to occur in one or more spots of a harness (Figure 10), it could usually be traced to uneven temperature and pressure on the platen face. It goes without saying that flat, parallel platens are a "must" for even, uniform pressure, particularly when fabricating very thin laminates.

2. Contaminated and/or Improper Copper Surface

We have done considerable work with both rolled and electro-deposited copper foil, and found that the former is best suited, where harnesses require 90 degree plus bend over a 1/16 inch radius. For

general purpose harness, where the softness and ductility of rolled copper is not required, we prefer to use electro-deposited copper.

We have investigated various surfaces of the copper to try to determine which gives us the best bond strength in this application. These surfaces include:

- 1 clean, non-treated surfaces, as received from the vendor;
- 2 mechanical and/or chemical cleaning of the surface, as received from the vendor;
- 3 treatment A (either one or both sides) as supplied by the vendor;
- 4 a chemical treatment that forms a dendritic copper oxide growth on the surface.

3. Release of Pressure at Too High Temperature

Pressure is used to effect an intimate contact between the surfaces to be bonded and to exclude air. Pressure must be maintained uniformly until the FEP Teflon is cooled sufficiently to change from the plastic to the solid state. In all of the prototype development work on these harnesses, the part was kept in the press under pressure until it cooled.

PEEL STRENGTH

The peel strength of the copper foil to the substrate, the etched copper circuit to the substrate, the cover layer to the substrate and the etched copper circuit become very important when determining whether a fabricated harness will pass quality requirements in environmental and mechanical testing. Considerable confusion exists within the industry when the term "peel strength" is used because it means different things to different people. There are at least three recognized and acceptable methods to test peel strength.

1. Peel or Stripping Strength of Adhesives (ASTM D-903-49, FED Test Method Standard 175, Method 1041.1).

This method requires that at least one of the adherend materials be flexible (both may be) enough to bend back on itself to a 180 degree angle over a small radius. The pull is at six inches per minute and the result is expressed in pounds per inch of width.

2. Climbing Drum Peel Test for Adhesives (ASTM D-1781, FED Test Method Standard 175, Method 1042-T).

This method requires that one adherend be sufficiently flexible to bend around a two inch diameter drum, and the other adherend be rigid. It is usually considered for testing under specified test conditions rather than fundamental measurements of adhesion per se. The drum is two inches in diameter and travels with a crosshead speed of one inch per minute which is equivalent to four inches of stripping from the assembly. Results are the average peel torque expressed in inch pounds per inch of width.

3. Peel Resistance of Adhesives (ASTM D-1876)

This method requires that both adherends be flexible, the top adherend being pulled at a 90° angle to the specimen and the bottom adherend being pulled at a 90° angle to the specimen (the two adherends are pulled at a 180° degree angle to each other). They are pulled at a crosshead speed of ten inches per minute. Separation of the bond line occurs five inches per minute. The result is expressed in pounds per inch of width.

There is a growing feeling in the industry that none of these tests reflect the information desired when referring to flexible harnesses and thin multilayer circuits. The information needed is the strength of the bond between two adherends when one is kept flat and horizontal and the other is pulled at a 90° angle at 1-20 inches per minute. The result should be expressed in pounds per inch of width or in grams per mil of width.

At Martin-Orlando, we have attempted to meet those requirements by using a modified Instron Model TTD (Figure 12).

Since the Instron is in constant demand, a small laboratory peel strength tester has been fabricated for screening tests only (Figure 12). The tester indicates pull by the deflection of a spring. It is an inexpensive piece of equipment which gives sufficiently accurate results for screening tests prior to final testing on the Instron.

EMBRITTLEMENT

During Kapton harness development, Martin-Orlando has found that, occasionally, a harness would be fabricated that had areas where the Kapton was not flexible. Instead, it was fragile and brittle and would crack and shatter with very little flexing. These areas were usually,

but not always, slightly discolored, a factor that could not be predicted. prior to final lamination of the cover layer.

This problem was investigated by both DuPont and Martin. Tests have shown that embrittlement can be artificially induced by subjecting Kapton to high humidity prior to lamination. Conversely, the condition can be eliminated by drying the film immediately prior to lamination. Certainly not all of the parameters affecting this condition have been established. We do not know exactly the percentage of moisture that must be present in the film to cause the condition. We do not believe moisture is the sole culprit. The problem might also be retained solvents and volatiles not completely or uniformly removed during the manufacture of the film. Our research engineers are working closely with DuPont in an effort to pin down these factors and eliminate the problem without employing an extra manufacturing process step.

TRIMMING

The problem of trimming the completed harnesses was first encountered in the prototype development program. All harnesses were fabricated in coordinated tools with master and auxiliary tool holes for maintaining registration and alignment. After final lamination, the harnesses were trimmed to their final configurations (Figure 13). This operation was done with a straight edge and an exacto knife on straight runs, and scissors on curves. Wherever possible, we tried to maintain a width of 0.125 inch minimum from any copper conductor or terminal pad.

Because of the toughness of the Kapton film and the human element involved, it was impossible to avoid minute nicks and tears in the film along the cut edge (Figure 14). These imperfections readily increased with the slightest bit of rough handling.

To overcome this problem, we turned to a sharp, smooth, steel rule die. We found that if the die was maintained, rejects due to human error could be eliminated. On a long manufacturing production run, a steel blanking die is recommended.

Another method we used to reduce tears in the harnesses was to design them so that there would be no sharp corners or V-cuts (Figure 15). By rounding the internal and external corners, we spread the stress over a relatively large area (minimum curve was 100 mils).

CONCLUSION

This paper has described the major problem areas encountered in the fabrication of Kapton flexible harnesses at Martin-Orlando. Although not all of these problems have been solved we are certain that we have been able to identify all the areas of concern in the development of advanced flexible harnesses. Since it is easily predictable that the use of flex harnesses will increase in the near future, it is equally simple to understand the urgency with which the entire field must be handled.

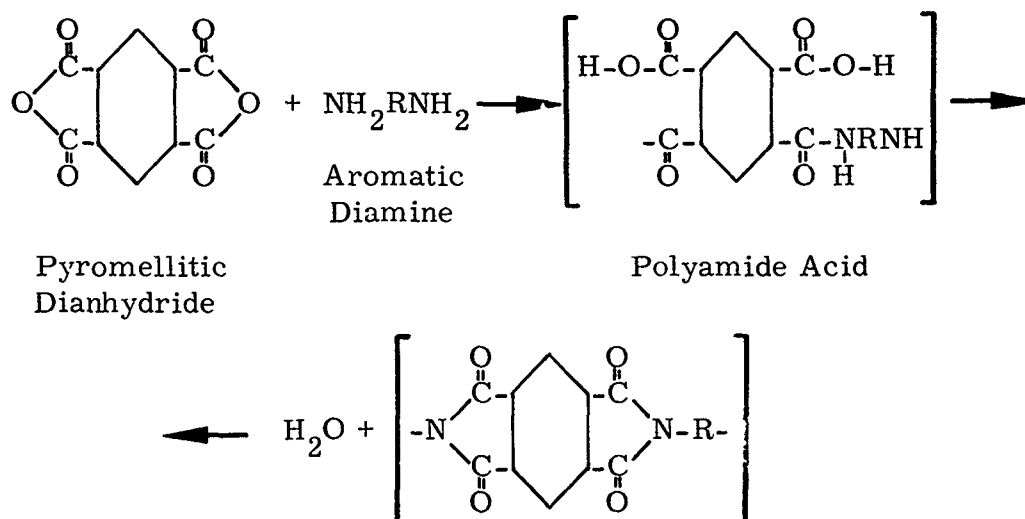


Figure 1. Polypyromellitimide

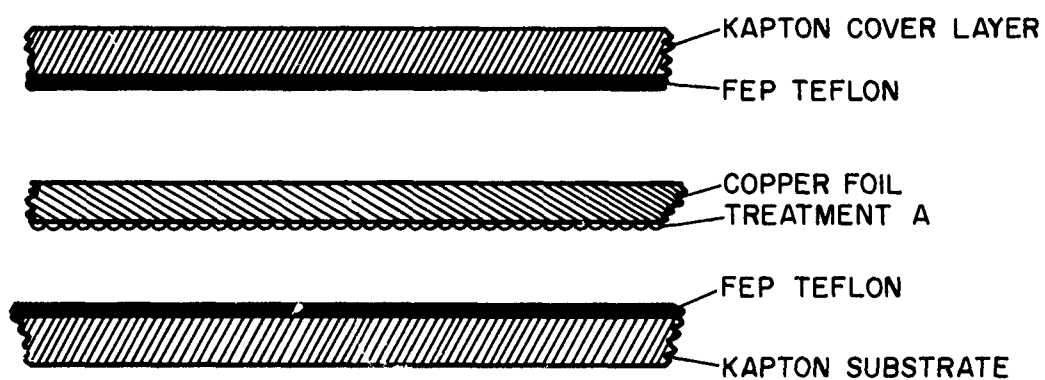


Figure 2. FEP Teflon Bonded to Kapton



Figure 3. FEP Teflon Bonded to Copper Foil

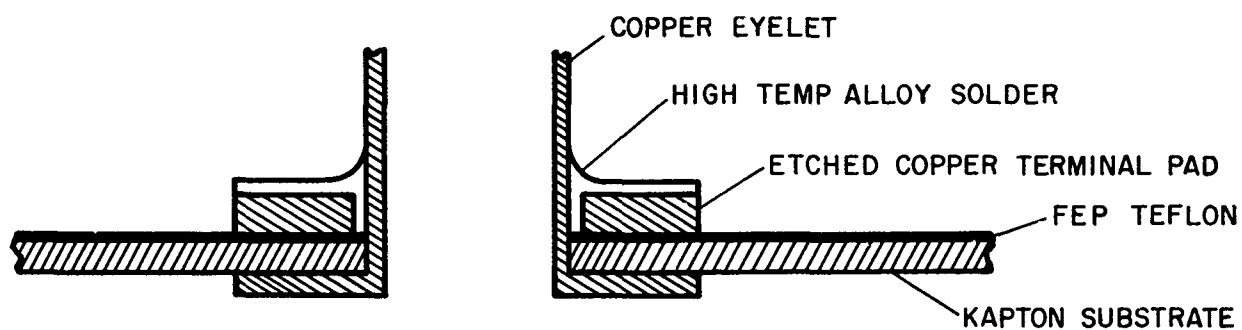


Figure 4. Eyelet Soldered to Terminal Pad Prior to Lamination

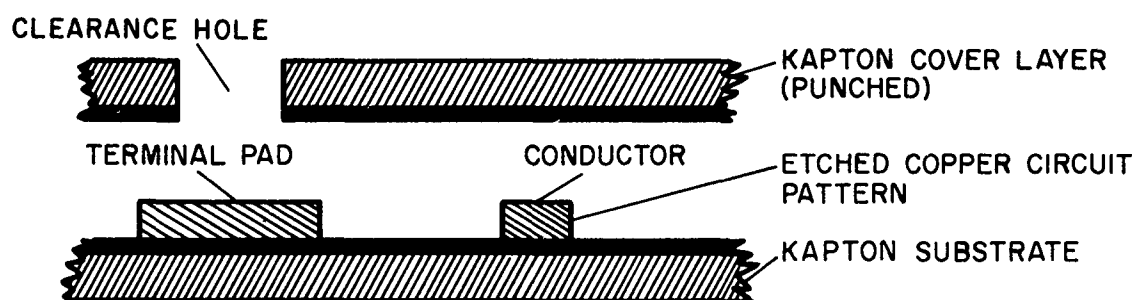


Figure 5. Clearance Hole in Cover Layer

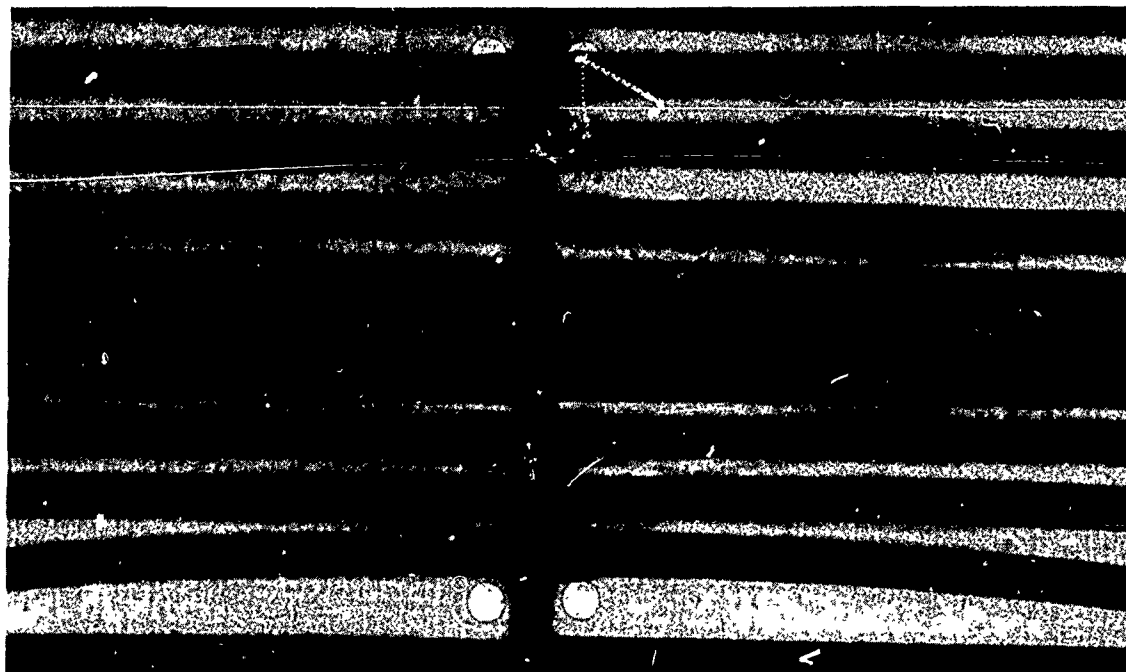


Figure 6. Misregistration of Sample

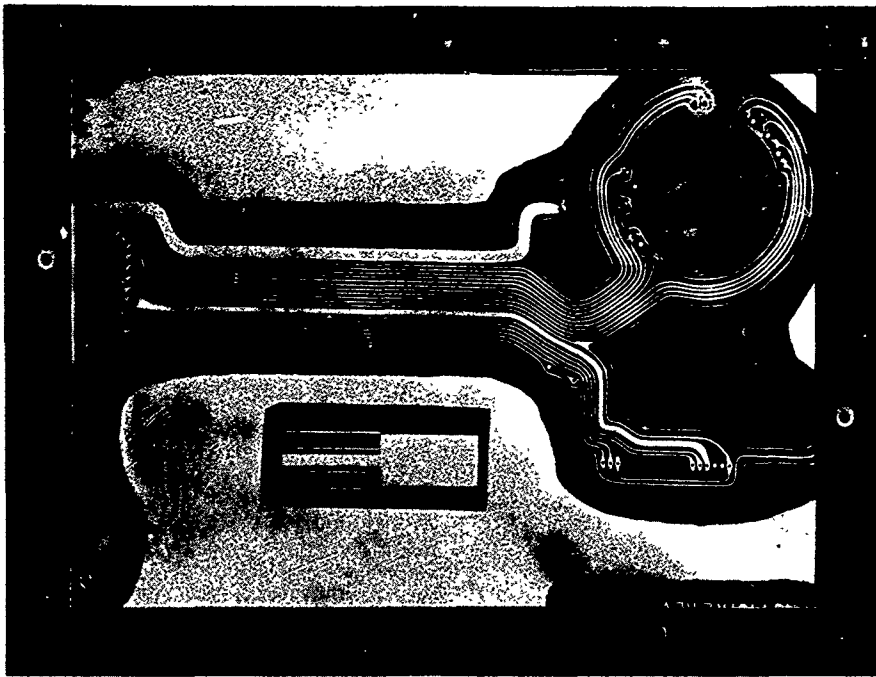


Figure 7. Special Etching Fixture

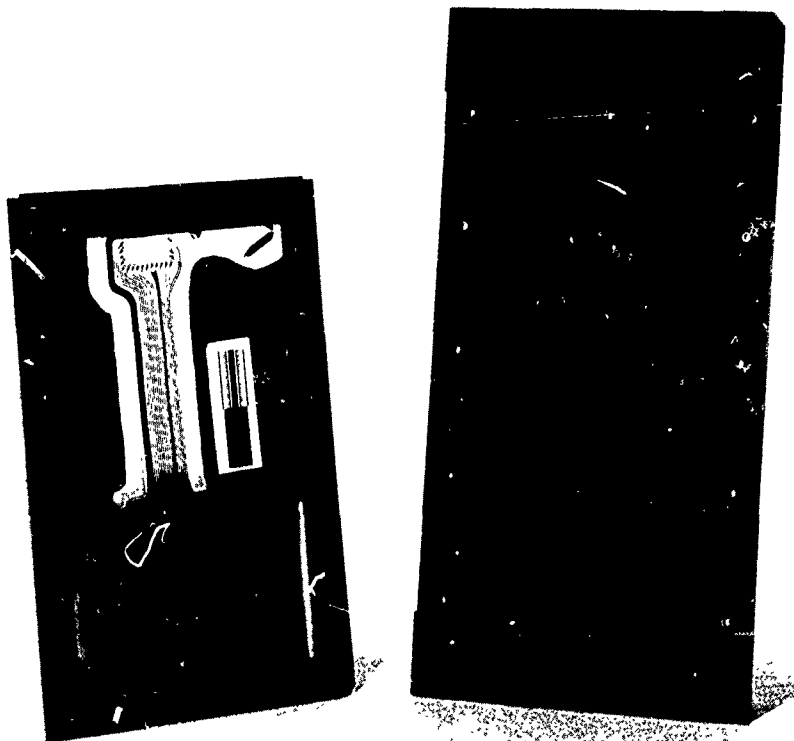


Figure 8. Fixture Top Frame and Part

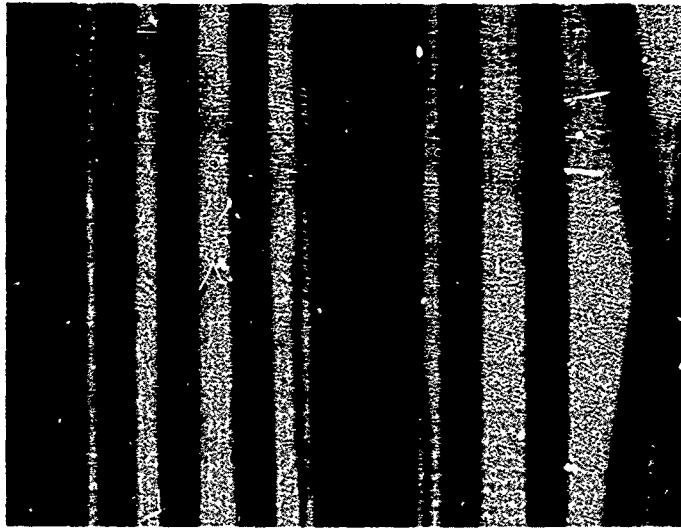


Figure 9. Misalignment

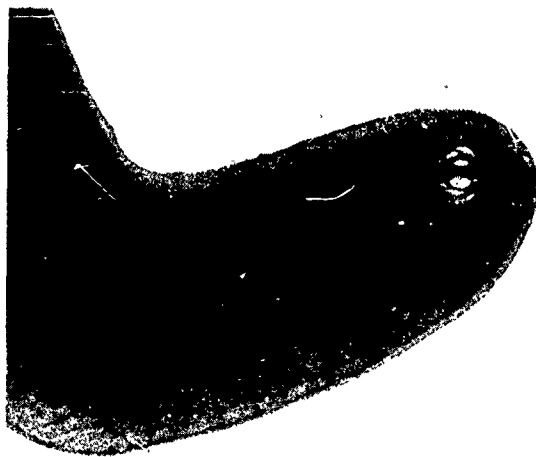


Figure 10. Delamination

Figure 11. Instron TTD

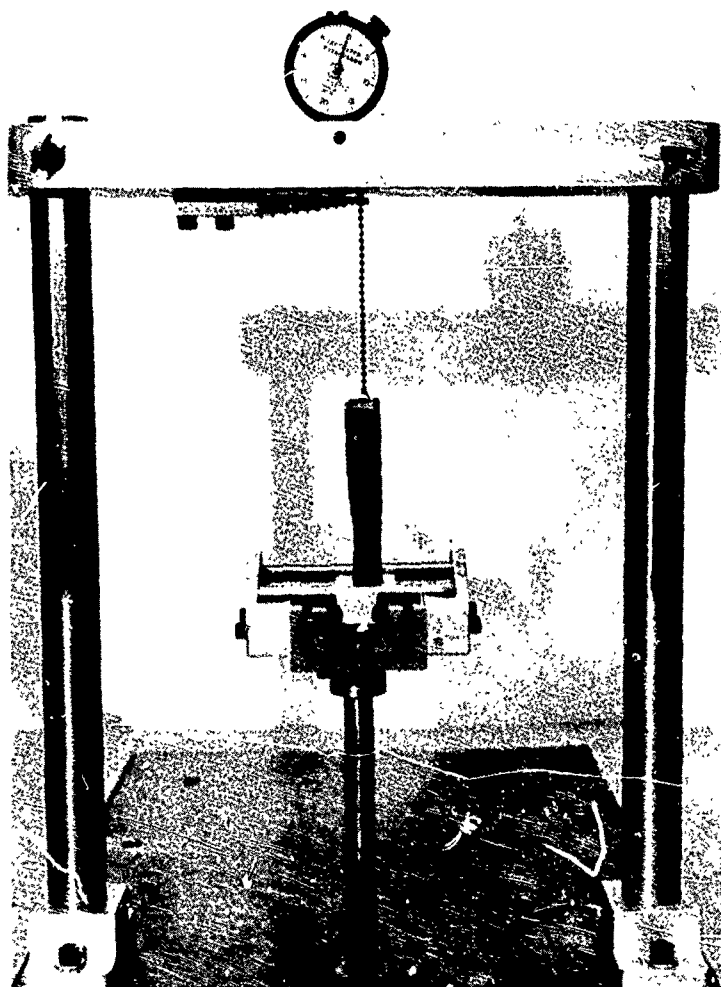
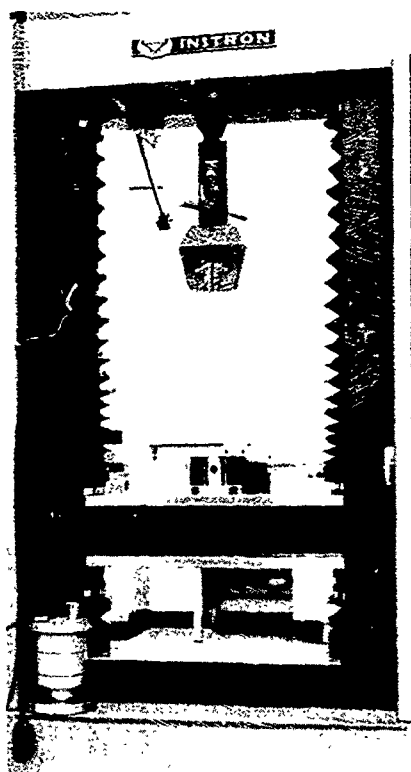


Figure 12. Peel Strength Tester

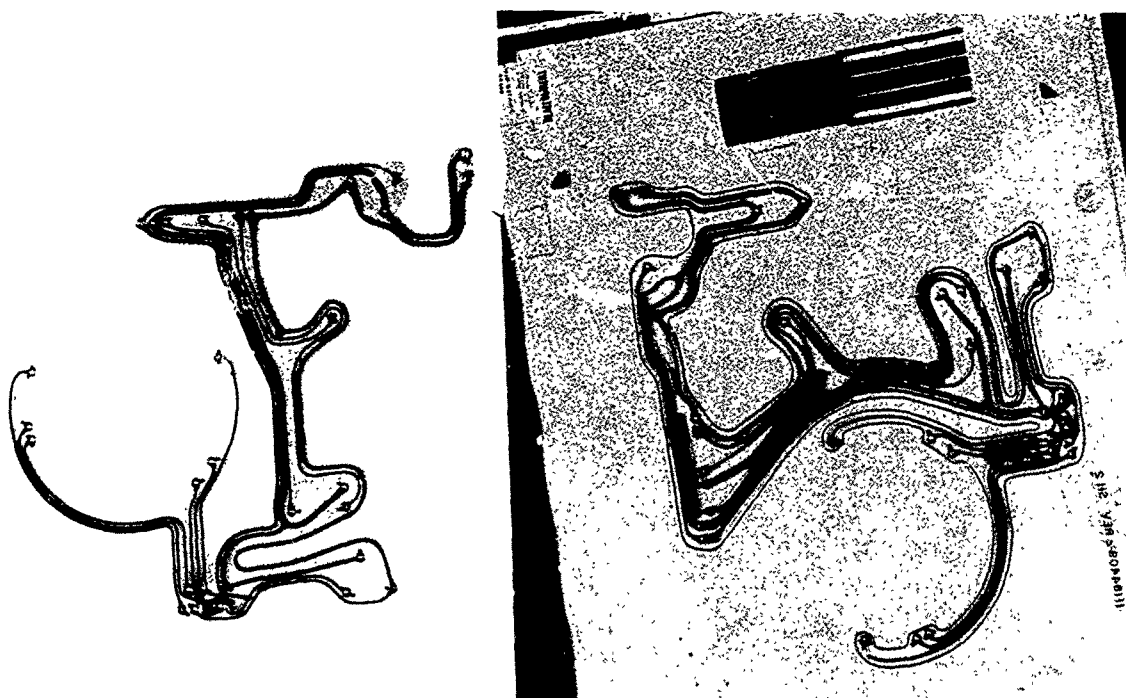


Figure 13. Harness Before and After Trimming

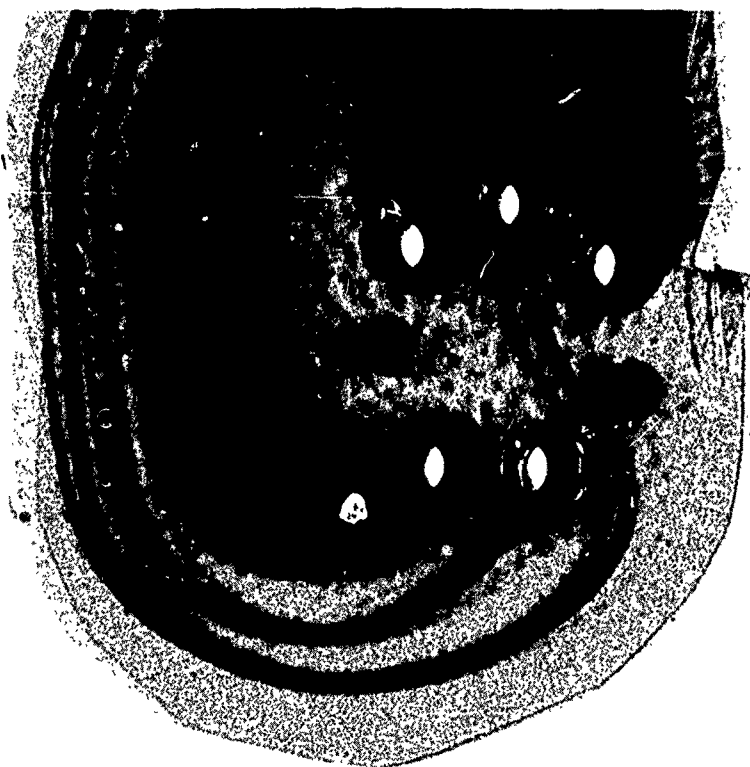


Figure 14. Nick in Cut Edge

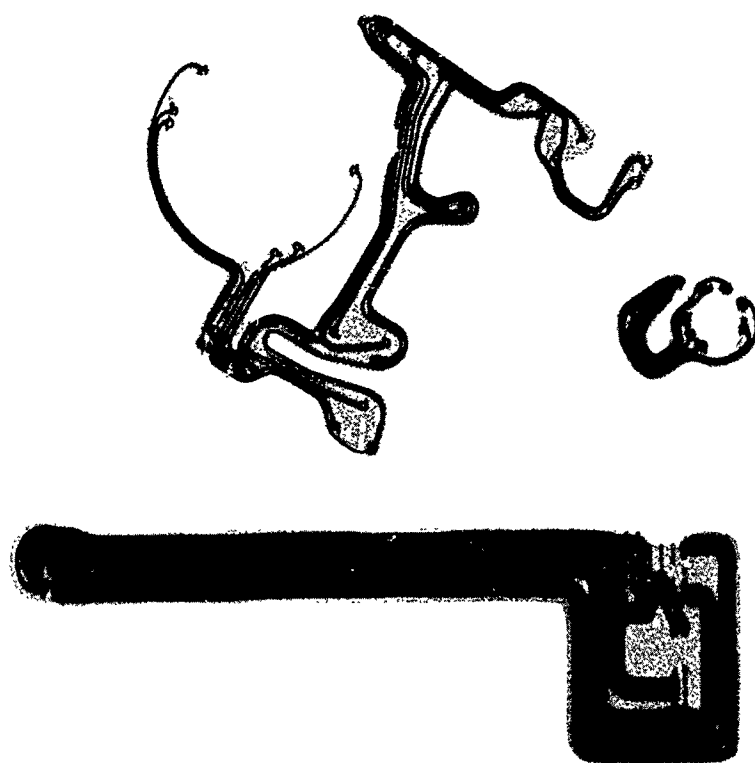


Figure 15. Examples of Harnesses